Human Factors and Safety Considerations of Night Vision Systems Flight

(Reprint)

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of Night Vision Systems Flight

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ABSTRACT

Military aviation night vision systems greatly enhance the capability to operate during periods of low illumination. After flying with night vision devices, most aviators are apprehensive about returning to unaided night flight. Current night vision imaging devices allow aviators to fly during ambient light conditions which would be extremely dangerous, if not impossible, with unaided vision. However, the visual input afforded with these devices does not approach that experienced using the unencumbered, unaided eye during periods of daylight illumination. Many visual parameters, e.g., acuity, field-of-view, depth perception, etc., are compromised when night vision devices are used. The inherent characteristics of image intensification based sensors introduce new problems associated with the interpretation of visual information based on different spatial and spectral content from that of unaided vision. In addition, the mounting of these devices onto the helmet is accompanied by concerns of fatigue resulting from increased head supported weight and shift in center-of-gravity. All of these concerns have produced numerous human factors and safety issues relating to the use of night vision systems. These issues are identified and discussed in terms of their possible effects on user performance and safety.

1. INTRODUCTION

In 1971, the Department of the Army adopted night vision devices (NVDs) for use in aviation. The purpose of these devices was to enhance the aviator's capability to operate during periods of low illumination. Since that time, the Army's doctrine of being able to carry out missions in darkness and under adverse weather conditions has resulted in the development and fielding of newer and more advanced night vision systems.

When the helmet is used as a platform for the presentation of flight imagery and symbology, certain characteristics become more important with regard to performance and safety. The visual input provided by these devices does not approach that experienced using the unaided eye during periods of daylight illumination. When compared to unaided daylight flight, many visual parameters, e.g., acuity, field-of-view, depth perception, etc., are understandably compromised when night vision devices are used. In addition, the mounting of these devices on the helmet increases the hazards associated with such physical parameters as weight and center-of-gravity.

2. HELMET MOUNTED NIGHT VISION DEVICES

In the aviation environment night vision imaging devices are mounted totally, or in part, on the aviator's helmet. A simplified block diagram of an NVD is shown in Figure 1. The two basic sections

are the sensor and the display. Currently, the two technologies used for night vision sensors are image intensification and thermal imaging (forward looking infrared-FLIR). Image intensifiers (I^2) amplify, or intensify, reflected or emitted light so the eye can more readily see a poorly illuminated scene and depend on the presence of some minimum amount of light in order to produce a usable image. This is analogous to using a microphone, amplifier and speaker to allow the ear to more easily hear a faint sound. In both cases some of the "natural fidelity" may be lost in the amplification process. The intensified image resembles a black and white television image, only in shades of green (due to the selected display phosphor), instead of shades of gray.

The second type of night imaging sensor uses thermal imaging. This type of sensor does not depend on levels of ambient light but, rather, on temperature differences, based on infrared (IR) radiation generated by the scene. The FLIR sensor can be designed to "see" radiation in either the 3-5 or the 8-12 micron spectral range. All objects radiate measurable amounts of IR energy in this spectral range. An important measure of performance of a FLIR sensor is the minimum temperature difference that the sensor can resolve. This measure is called the minimum resolvable temperature (MRT).

The U.S. Army has fielded two night vision systems for aviation use based on the image intensifier tube. The first is known as the AN/PVS-5 Series Night Vision Goggles (NVG) and is based on second generation image intensifier tubes. The second, which utilizes third generation tubes, is known as the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) (Figure 2).

The original version of the AN/PVS-5 NVG was a full face configuration. However, this design possessed several deficiencies for aviation, the major one being that the aviator's peripheral vision was totally occluded. This lack of peripheral vision was a major safety concern to the aviation community. In 1982, a modified faceplate version of the NVG, shown in Figure 3, was developed.[1]

The NVG and ANVIS systems are imaging devices that amplify low level ambient light reflected from objects. An amplified image is presented on a phosphor screen.[2] Both systems use two image intensifier tubes to form a binocular device which is attached to the aviator's helmet.

The second generation NVGs have a typical system gain of 2,000 to 3,000 and a peak display luminance between 0.3 and 0.9 footlamberts. The third generation tubes in the ANVIS operate similarly to the second generation, but they have greater sensitivity and resolution, operate over a slightly different spectral range, and have a peak display luminance of between 0.7 and 2.2 footlamberts. For cockpit lighting compatibility, the interior surfaces of the objective lenses of ANVIS are coated with a dielectric film (a minus-blue filter) that rejects wavelengths less than 625 nanometers. From the user's point of view, the major difference between NVGs and ANVIS is that ANVIS, with third generation tubes, is usable during periods of lower light levels where starlight is the only source of illumination.

In the Army's newest production aircraft, the Apache helicopter (AH-64), the helmet mounted display used, known as the Integrated Helmet and Display Sighting System (IHADSS) (Figure 4), receives its input from the Pilot Night Vision System (PNVS), a thermal imaging sensor operating in the 8-12 micron spectral range. This sensor is mounted on the nose of the aircraft. The display which produces the image of what the sensor "sees" is a miniature (1 inch diameter) CRT mounted on the aviator's helmet. Imagery produced on the CRT is relayed optically through a series of lens elements and reflected off a beamsplitter into the aviator's eye. The CRT and relay optics, referred to as the Helmet Display Unit (HDU), are mounted on the right side of the aviator's helmet, providing imagery in a monocular format. The IHADSS display is designed to provide a one-to-one presentation of the 30 degrees vertical by 40 degrees horizontal field-of-view provided by the sensor.

The following discussions address the major characteristics of one of these night imaging technologies, image intensification. Helmet mounted systems based on image intensification technology are light amplification devices. A minimum amount of ambient light must be available for acceptable performance. The NVGs and the ANVIS are two I^2 systems currently used in aviation. Paramount in the discussions is the possible influence of these characteristics on user performance and safety.

3. HEAD SUPPORTED WEIGHT

The placing of the NVDs on the helmet has increased significantly the amount of weight which must be supported by the head. The head supported weights of the cutaway version of the NVG and ANVIS when worn with the SPH-4 aviator's helmet are 6.8 pounds (3.1 kg) and 5.9 pounds (2.7 kg), respectively. These weights include typical values of counterweights used by aviators to offset center-of-gravity (CG) shifts.

The effects of placing additional weight on the aviator's head generally can be grouped into two areas: fatigue and crash dynamics. Very little research has been done to document the fatigue factor associated with increased head supported weight. One study, conducted in 1968 by the U. S. Army Human Engineering Laboratories found that a total head supported weight in excess of 5.3 pounds (2.4 kg) degraded the performance of complex sighting tasks.[3] This degradation manifested itself in slower head motions, most likely the result of muscle strain. Fatigue in the head-neck muscles can slow reaction times associated with movements of these muscle groups. In situations where the primary pilotage imagery input is controlled by head movement, this slowing of reaction time creates a dangerous condition and also may contribute to decreased maneuvering accuracy. However, the quantitative relationship between weight and performance degradation is not documented.

The effect of increased head supported weight in crash dynamics is a direct result of the additional mass. For the 50th-percentile male head, the head and neck weight is 11.7 pounds. In the case of AN/PVS-5 NVG mounted on the SPH-4 helmet with counterweights, an additional 6.8 pounds result in a 58 percent increase in head supported weight and accompanying G-force in a crash. This increased G-loading will further contribute to head and neck muscle fatigue during maneuvers of low to moderate accelerations (< 5G). However, of most concern is the additional amount of G-force which will act during crashes. In the absence of external forces and neglecting forces due to the neck muscles, the total internal force exerted on the skull base during acceleration is approximately equal to the product of the total mass of the helmeted head and the head acceleration. Thus, for a given head acceleration, the larger the mass (head supported weight), the larger the force and risk for injury.

It must be pointed out that the current NVDs (and their accompanying counterweights) are designed to break away at specified G-levels. For example, the ANVIS should break away from the aviator's helmet at a head acceleration of 10-15 G. The purpose of this type of design for NVDs is to reduce the total head/neck/HMD mass during the critical period of high accelerations.

4. CENTER-OF-GRAVITY

Both NVG and ANVIS are attached to the front of the helmet. Both of these systems cause a shift in the location of the center-of-gravity of the head/neck/NVD system and result in an asymmetrical loading of the head/neck system. A shifted center-of-gravity affects the same areas as weight: fatigue and crash dynamics. The offset center-of-gravity creates a moment arm by which the weight of the head/neck/NVD system produces a torque on the head/neck muscle group. The effort required to balance this torque contributes to fatigue. According to a study addressing various center-of-gravity positions for aviation helmets, aviators preferred rearward and vertical CG shifts to forward and sideways shifts.[4] These conclusions are in conflict with a previous study which concluded that less fatigue was found for sideways and forward shifts.[5] The current ANVIS and NVG have forward shifts. Although there is disagreement between which type of CG offset is best tolerated, any amount of offset most likely will increase fatigue which will further degrade performance during extended missions.

With respect to the dynamics of a crash, if no external forces are present and the effects of the neck muscles are again neglected, the torque at the skull base is approximately equal to the product of the mass of the head/neck/NVD system, the linear acceleration, and the distance from the head/neck center-of-gravity to the head/neck/NVD center-of-gravity. Thus, for a given head combination of head supported weight and acceleration, the greater the CG offset, the greater the torque and risk of injury.

As can be deduced from the above discussions, the effects of head supported weight and a shift in the CG are not independent. An increase in either parameter increases the torque or bending stresses in the neck due to maneuver flight loads and/or crash loads. In the design of future systems, it is imperative that the NVD CG be as close to the head/neck CG as possible to reduce fatigue and risk of injury.

5. VISUAL ACUITY

Visual acuity is a measure of the ability of the eye to resolve spatial detail. Snellen visual acuity commonly is used and is expressed as a comparison of the distance at which a given set of letters are correctly read to the distance at which the letters would be read by someone with clinically normal eyesight. A value of 20/80 indicates that an individual reads at 20 feet the letters normally read at 80 feet. Normal visual acuity is 20/20. Snellen visual acuity with the AN/PVS-5 NVG is 20/50 under optimal conditions (high contrast and scene luminance). Snellen visual acuity with the AN/AVS-6 ANVIS is 20/40 under optimal conditions. But, these optimal conditions will seldom be encountered by an aviator in the real world.

Visual acuity, as measured through an I^2 NVD, is a subjective measure of the operator's visual performance using these devices. In contrast, resolution is an objective measure of the capability of an I^2 NVD to distinguish a separation between two objects. Night vision device procurement, test, and end-of-life specifications are defined in terms of resolution rather than visual acuity.

Optimal I^2 NVD resolution is obtained under high light level conditions with high contrast targets. The resolving power of the I^2 NVD decreases with light level because the noise in the intensified image increases. The high light level resolution limit was stated earlier as equating to a visual acuity range of 20/40 to 20/50. The low light level resolution is not limited, but continues to decrease with decreasing light levels. Remember, image intensifiers are light amplification devices, requiring a minimum level of illumination to function effectively. Although there may be measurable resolution at very low light levels, the NVGs lose their operational effectiveness at about starlight, as visual acuity approaches 20/100, and ANVIS lose their operational effectiveness at overcast starlight.

In order for the aviator to take full advantage of the I^2 NVD's resolution capability, the eyepiece lenses in front of each eye must be adjusted to suit the wearer's eyes. Each eyepiece lens is independently adjustable over a range from +2 to -6 diopters. This adjustment may eliminate the need for some aviators to wear their spectacles when using I^2 NVDs. Aviators still may require spectacles to correct astigmatism or to see items in the crewstation under the I^2 NVDs.

6. BIOCULAR VS. BINOCULAR PRESENTATION

The human visual system is binocular in nature. A binocular system receives two visual inputs from two sensors which are slightly displaced in space. This configuration is used in the AN/PVS-5 Series NVGs and AN/AVS-6 ANVIS where two separate image intensifier tubes, one tube for each eye, are the sources of the visual input. A variation in this design is a biocular system where one visual input is presented to both eyes using mirrors or prisms. This configuration is used in the AN/PVS-7 Series NVGs were one image intensifier is the source of visual input and the same image is presented to both eyes. The AN/PVS-7 may be used by crewmembers, but is not authorized for use by aviators.

Image intensifiers present "noisy" images to the eyes. This noise appears as scintillations, commonly called sparkles or snow. The noise increases as the ambient light level decreases. The noise is more predominant with second generation image intensifiers than with the more sensitive third generation image intensifiers. These scintillations block detailed information in the image. Since the intensity and location of the noise varies with time, it is unlikely that a scintillation will appear at the same place at the same time in both tubes. The observer therefore benefits from having two independent (uncorrelated) images in a binocular system compared to the duplication of the same (correlated) image in a biocular system. Therefore, there is a theoretical improvement in perceived image quality due to visual noise reduction in the binocular system compared to a biocular system.[6]

Binocular systems also present a brighter image to the viewer than biocular systems since the luminance output of the image intensifier in a biocular system is divided with half presented to each eye. An additional reliability benefit, particularly in aviation, of binocular systems is redundant image intensifiers. Increased cost, weight, and complexity are obvious detractors of binocular systems compared to biocular systems.

Binocular systems might be expected to provide the additional visual capabilities of depth perception and stereopsis such as with the unaided eyes. Depth perception is the ability of a viewer to judge the relative location of objects in space. Stereopsis is the ability of the observer to judge depth based purely on the differences in the two retinal images caused by the separation of the two eyes. However, the ANVIS and NVG binocular feature does not enhance the ability of users to perceive depth.

Depth perception with NVGs approximately is equal to that of the monocular unaided eye.[7] Size consistency, overlay, interposition, motion parallax, shadows, and convergence of lines are monocular cues used for depth perception. Resolution also plays an important role in depth perception. The viewer can extract better monocular cues from a scene using an I^2 NVD with better resolution, thus enhancing the viewers's ability to judge relative distances. The ANVIS provides better depth perception cues than NVGs since ANVIS provides better resolution. Accommodation, convergence, and divergence are weak binocular cues used for unaided eye depth perception that are unavailable to night vision device users.

As stated above, stereoscopic vision results from images collected from two slightly different perspectives, such as with the two displaced eyes. Stereoscopic vision is used primarily in eye-hand coordination tasks and is most effective at ranges of less than 50 feet. Experiments with binocular and biocular NVGs (AN/PVS-5 Series vs AN/PVS-7 Series) have demonstrated that the image disparity obtained by the separation of image input in the binocular system does not provide effective stereoscopic vision. There was no statistically significant performance difference between the binocular and biocular systems.[8] Neither does ANVIS offer effective stereoscopic vision.

The aviator's ability to judge depth using I^2 NVD is critical particularly during confined area maneuvers such as in parking areas and landing zones, and during hovering, bob-ups, and nap-of-the-earth flight. The depth perception cues available are, at best, equivalent to performing these maneuvers with one eye during the day.

In the human visual system, the eyes work together and change their focus together from about 6 inches to infinity. This variable focusing ability can occur consciously or unconsciously and is quite rapid. The objective focus on a night vision devices is quite different. The objective lenses on each channel are manually focused independently from about 10 inches to infinity (distances greater than 50 feet are equivalent to infinity for I^2 NVDs). The aviator must view an object greater than 20 feet away when focusing the objective lenses for distant viewing. Misadjusting the objective lenses will greatly reduce the ability of the aviator to view distant objects clearly. The objective lens of one or both channels must be manually adjusted to view objects closer than 20 feet through the I^2 NVD. The aviator does not need to refocus the I^2 NVD for viewing inside the crewstation because of the look-under capability of the I^2 NVDs.

7. FIELD-OF-VIEW AND VISUAL FIELDS

The human eye, as a sensor, has an instantaneous field-of-view (FOV) which is oval in shape and typically measures 120 degrees vertically by 150 degrees horizontally. When two eyes are used, the overall FOV measures approximately 120 degrees vertically by 200 degrees horizontally.[9] In both NVGs and ANVIS, the FOV of a single image intensifier tube is a circular 40 degrees. The tubes have a 100 percent overlapping, hence the combined field is also a circular 40 degrees. A pictorial representation of the 40 degrees FOV for ANVIS and NVG is provided in Figure 5.

The circular 40 degree FOV seems small when compared to the overall FOV of the eyes, but the reduction is not as significant when compared to the aviator's unobstructed view of the outside world from

the design eye position in most aircraft. Still, the aviator must use continuous head movements in a scanning pattern to help compensate for the limited I^2 NVD FOV.

The effects of the reduced FOV on performance are not fully understood. The problem of determining a minimum FOV required to fly is not a simple one. First, the minimal FOV required is extremely task dependent. This becomes obvious when one considers the narrow FOV used in high speed transition flight versus that used in clearing the rotor blade during a hovering maneuver.

The 40 degree FOV of the I^2 NVD is a theoretical value based on the user being able to place his eye into the exit pupil of the I^2 NVD optics. Variations in head anthropometry and wearing protective mask or corrective lenses may prevent proper eye placement, resulting in a reduced FOV. Improper adjustment of the helmet attachment can also preclude the aviator from achieving a full 40 degree FOV. These small FOV losses are not always obvious to the aviator.

Current I^2 NVD designs extend the visual field besides that provided through the I^2 NVD optics. Instruments and other objects within the crewstation can be viewed by virtue of the I^2 NVD's limited look-under, look-around capabilities. However, the eyes are adapted to the light emitted by the image intensifiers. Supplemental lighting at a level equivalent to the output of the I^2 NVD is necessary for the aviator to see detailed scenes such as maps and dial legends.

8. SENSOR PARAMETERS

There are several measurable parameters that affect the performance of the image intensifiers in I^2 NVDs. These include spectral response, signal-to-noise (S/N) ratio, equivalent background input (EBI), sensitivity, and gain. There are also defects in the image intensifier tubes that can degrade their performance. Some of the tube characteristics are fixed at the time of manufacturing and others change during the lifetime of the tube. When the tube is manufactured, it has a certain spectral response based on the chemical composition of its photocathode. Second and third generation tubes have the spectral response shown in Figure 6. Second generation tubes are responsive to wavelengths between 380 and 850 nanometers, which includes all of the visible spectrum. Third generation intensifiers are responsive to wavelengths between 550 to 950 nanometers, which includes only a portion of the visible spectrum, but extends further into the near infrared. Even though objects appear to have the same shape when viewed through the two different generation tubes, they may have entirely different intensities. For example, dirt roads against green grass appear very dark through second generation tubes, but appear bright through third generation tubes. This type of contrast reversal is common when comparing second and third generation images. The contrast, and therefore, the visibility of objects must be related to a specific generation device.

The contrast and resulting image quality also are a function of the signal-to-noise ratio of the intensifier tube. Signal is the information transmitted through the intensifier. Noise is unwanted disruptions to the signal. Some effects of visual noise were discussed earlier in Section 6. The S/N ratio decreases as the image intensifier tube ages. Second generation tubes have lower S/N ratios than third generation tubes. The S/N ratio of second generation tubes continue to decrease throughout their 2,000-4,000 hour useful life. The S/N ratio of third generation tubes tends to remain constant over their 7,500 hour life and then falls off rapidly. End-of-life is defined as the point when the S/N ratio falls below a prescribed value.

Another important factor affecting image quality is equivalent background input (EBI). EBI is a measure of the output luminance of an image intensifier with no input. This parameter is important because if the EBI is too high, the contrast of the intensified image may be too low for the aviator.

The sensitivity of an image intensifier, whether second or third generation, is established when it is manufactured. The sesitivity of second generation intensifiers gradually decreases over time. Third generation intensifiers maintain a relatively constant sensitivity over time. The eventual loss of sensitivity results in a weakened signal, thus a lower S/N ratio, which signifies end-of-life.

The gain of an image intensifier is defined as the ratio of signal (light) in to signal (light) out. Tube gain is controlled primarily by the tube's power supply. Increasing the voltage between elements in the intensifier tube increases its gain. When the tube is new, increasing the gain increases both the signal level and the noise level. At some point in time near end-of-life when the sensitivity of the tube is low, increasing the gain increases the noise more than the signal, thus decreasing the S/N ratio.

Other characteristics affecting image quality are tube defects. Some minor defects are normal and may be present when the tubes and systems are accepted from the manufacturer; others develop during the life of the device. Some black spots, fixed pattern noise, and distortion are permissible in new image intensifiers. The tube specifications define the limits of acceptable defects.

The size, location, and number of black spots are measured and compared with a specification to determine if they are acceptable. Large spots in the central area of the image large enough to block objects from view, such as other aircraft, are unacceptable. Fixed pattern noise may appear as a faint geometrical pattern of the internal fiberoptics. If the presence of the pattern interferes with the aviator's ability to use the I^2 NVD, the tube is rejected. Finally, excessive distortion of the internal fiberoptic inverter is measured. Unacceptable distortion levels can cause flat surfaces to appear to have depressions or bulges. Tubes exhibiting this level of distortion are obviously unacceptable for flight.

The aviator always has the right to reject any I^2 NVD for flight because it has unacceptable performance characteristics. There is an established routine inspection schedule for I^2 NVD to ensure they are performing properly. Presently, the ANVIS are inspected visually and tested every 30 days, and NVGs used for aviation are visually inspected every 90 days (based on the limited availability of test sets).

9. ENVIRONMENTAL CONSIDERATIONS

Environmental conditions can affect greatly the performance of I^2 NVDs. These conditions include illumination, weather, cloud cover, and obscurants. Some environmental conditions can enhance and others can degrade I^2 NVD performance. As stated earlier, I^2 NVDs are amplification devices. A minimum amount of energy is necessary for acceptable performance. Major sources of this energy are the moon, stars, and artificial lighting.

Energy from natural sources such as the moon and stars, and energy from artificial sources such as nearby towns or tactical flares reflect from objects. The composition, surface characteristics, and environmental conditions determine the amount and spectral distribution of the reflected energy that reaches the I^2 NVD. The I^2 NVD's objective lens characteristics determine the amount and spectral distribution of the energy which is transmitted to the photocathode (light sensitive portion of the image intensifier tube) of the I^2 NVD. The chemical composition, age, and voltage of the photocathode determine characteristics of the reflected energy which finally is presented to the viewer.

The moon and stars emit a significant amount of energy that cannot be seen by the human eye, but can be seen by the I^2 NVDs. The stars are a uniform omnidirectional source of energy. The moon, like the sun, is a point source of energy that casts shadows as it moves across the sky from moonrise to moonset. The percent of moon illumination, rise and set times, and the maximum moon angle above the horizon are data available from the weather service for a specific geographical area.

The direction of flight with respect to the location of the moon, sky glow, and ground lighting is critical to I^2 NVD performance. Flying toward light sources will reduce the effectiveness of the I^2 NVD, similar to flying toward the sun during daylight. Flying away from the light sources may enhance the I^2 NVD image. Shadows cast by terrain features and manmade objects from the external lighting are important considerations for the aviators. Most wires are not detectable through I^2 NVDs, but often their support poles and towers provide cues to the existence and path of the wires. The configuration of the external lighting with respect to the aircraft's direction of flight can enhance or mask the shadow cues.

Atmospheric conditions also can have a significant effect on I^2 NVD performance. The energy reflected from objects is scattered by water vapor and particulate matter suspended in the air. Optimal performance is obtained on a dry, clear night. The presence of precipitation (e.g., rain and snow) and obscurants (e.g., fog, dust, and smoke) degrade the performance to varying degrees. In general, atmospheric conditions that degrade unaided visual performance will also degrade the performance of I^2 NVDs.

Aviators with minimal I^2 NVD experience often overextend themselves by failing to recognize the gradual degradation in their NVD's performance due to deteriorating atmospheric conditions. One feature of I^2 NVDs is that they maintain a constant average display luminance over a wide range of input energy. Therefore, it may not be obvious to the aviator that conditions are deteriorating. The experienced I^2 NVD aviator has learned that deteriorating environmental conditions are indicated by an increase in image noise. High visual noise levels indicate the device is operating at its performance limits.

The presence of cloud cover can increase or decrease the amount and distribution of predicted energy available to I^2 NVDs. Cloud cover may attenuate the energy from natural sources but enhance the amount of energy available from artificial sources, such as sky glow from towns, shopping centers, and highway lighting.

Modern artificial lights, e.g., high efficiency sodium and mercury vapor lamps, by design, produce a large percentage of their energy in the visual portion of the spectrum. Second generation image intensifiers are sensitive to all of the visual spectrum and can see all of the artificial light, but the third generation image intensifiers see only a part of the visible spectrum, and hence, only a part of the artificial light. Therefore, energy generated by artificial sources may be more beneficial to second generation I^2 NVDs than to third generation devices.

Current Army policy restricts I^2 NVD flights to periods of natural illumination which meet or exceed the lunar conditions of 23 percent fractional illumination and 30 degrees altitude above the horizon. These conditions can be waived when the aircraft is equipped with an artificial infrared search or landing light. This policy was implemented when only second generation devices were available. It does not require the aviators to use the infrared light, but they must have it available. The policy has not changed with the fielding of the more sensitive third generation devices.

When selecting the correct lamp wattage and dispersion pattern to be used with an infrared filter in the search or landing light with the I^2 NVD, it is critical to consider the environment in which the aircraft will be flown. Some lights generate large area footprints of low intensity and others generate small footprints of light with high intensity. In either case, there is a tendency to become channelized by the infrared light, similar to driving at night with headlights. The aviator becomes less aware of the periphery and significantly limits the peripheral visual scans.

10. INTERNAL AND EXTERNAL LIGHT SOURCES

Once the aviator is assured the I^2 NVD is operating properly and the environmental conditions will permit I^2 NVD flight operations, the next major concern is the crewstation lighting environment in which the I^2 NVD will be used. Proper internal crewstation lighting is critical to the overall effectiveness of the I^2 NVD. Because I^2 NVDs based on image intensification operate on the principle of light amplification, bright lights emitting energy in that portion of the electromagnetic spectrum in which these devices are sensitive produce severe veiling glare that can obscure the overall image and degrade the performance of the I^2 NVD.[10] To prevent this, and to protect the image intensifier assembly from permanent phosphor burns, both NVGs and ANVIS are equipped with a bright source protection (BSP) circuit, which operates as an automatic gain control. The BSP circuit decreases the sensitivity of the image intensifier tubes when they are exposed to bright lights emitting energy in the ANVIS/NVG-sensitive portion of the electromagnetic spectrum. The net result is a reduced response to energy originating from external scene, effectively reducing the aviator's capability to view outside the cockpit.

Numerous methods, i.e., low-reflectance black paint, light louvers, filters, low intensity lamps, etc., have been attempted to provide "compatible" cockpits.[11] However, only limited success has been achieved using any of these methods. A design solution to this problem is incorporated in the ANVIS. The interior surface of the objective lenses in the ANVIS have been coated with a dielectric film (called a "minus-blue filter") that would reject wavelengths less than 625 nm. This design was planned to make the ANVIS compatible with cockpits having blue-green crewstation lighting. However, programs to convert current aircraft to blue-green lighting have not been fully implemented. Therefore, some aircraft are currently being flown without compatible lighting as specified in MIL-L-85762, "Lighting, aircraft, interior, night vision imaging system compatible."[12]

Flares, rocket motors, strobe lights, lightning, and other bright light sources may affect temporarily the performance of the I^2 NVD. The interruption may last only a few seconds, but if unexpected, the interruption of the image presentation may be quite disconcerting. A bright flash will cause the image intensifier to saturate, evidenced by a temporary, but complete, loss of detail in the intensified image. Since saturation limits the light passed to the eye, recovering from a flash through an image intensifier is much more rapid than recovering from a flash to the unaided dark adapted eye.

As stated earlier, the output image of the I^2 NVD is presented to the viewer on a green phosphor screen. All color information from the surrounding environment is converted to shades of green analogous to the imagery in black and white television. This is particularly important when considering color coded information from external light sources, such as aircraft navigation and tower lights. The lights on an approaching and departing aircraft look the same. Color coded taxiway and runway lights appear the same through an I^2 NVD, too.

Intensity and distance cues easily are confused at night, particularly with I^2 NVDs. A light source can appear the same to an aviator whether it is small and close, or large and far away. Lights from other aircraft can blend easily into ground lights. Midair collisions have resulted because aircrews were not able to differentiate lighted aircraft in their flight path from background lights.

Anticollision strobe lights improve the conspicuity of aircraft, but not without trade-offs. Often, the high intensity xenon strobe lights interfere with the I^2 NVD and distract the aviators because their light reflects off the rotor blades and nearby objects in terrain flight. The front 180 degrees of the anticollision light is covered with tape to prevent the unwanted reflections. During formation flight, only the trailing aircraft can use an anticollision light since other aircrafts' strobe lights would be in the view of aviators in the back of the formation. The upper position lights have their lower hemisphere taped and the lower position lights have their upper hemisphere taped to reduce unwanted external light from entering the crewstation. Some newer aircraft use small near infrared lights, visible only with I^2 NVDs, to covertly mark their position without interfering with the I^2 NVD.

Light from internal and external sources scatter off of dirt, grease, moisture, and abrasions on the windscreen and reduce the contrast of the intensified scene. Clean, dry, and unabraded windscreens are essential to optimum I^2 I^2 NVD performance. Using the night driving analogy is again appropriate. Oncoming headlights through a dirty, wet, pitted windshield cause the same visual degradation. Information concerning the optical condition of the windscreen and other transparencies prior to an accident would be beneficial in determining if the condition of the transparencies was a factor in the accident.

11. FAILURE MODES

The binocular design (two independent channels) of the I^2 NVDs used for aviation provide an inherent redundancy for the optics and image intensifiers. However, an aviator is more likely to experience a battery failure than a image intensifier or optical element failure. Battery redundancy is provided by a dual battery pack with a selector switch for the primary or spare battery. Battery failure initially will cause both intensifiers to exhibit luminance variations, followed by a complete failure of both

intensifiers. The aviator can recover from this failure simply by moving the selector switch to the spare battery position. A luminous low battery indicator on the ANVIS mount signals eminent battery failure.

A gradual single image intensifier failure is more likely to occur than a catastrophic failure of one or both intensifiers. The battery and intensifier redundancy features significantly enhance the I^2 NVD reliability by duplicating system components that have a greater chance of failure over time than other components. Other I^2 NVD components may have a higher probability of failure in the shipping, maintenance or assembly, but not during flight operations.

12. SUMMARY

Night vision devises based on I^2 technology allow aviators to fly during ambient light conditions which would be extremely dangerous, if not impossible, with unaided vision. While these devices do not change night into day, they do significantly enhance night operations compared to the unaided eye. With night vision devices, compromises must be accepted in many visual parameters, e.g., acuity, field-of-view, depth perception, etc., and the effects of these compromises on performance must be understood.

13. ACKNOWLEDGMENTS

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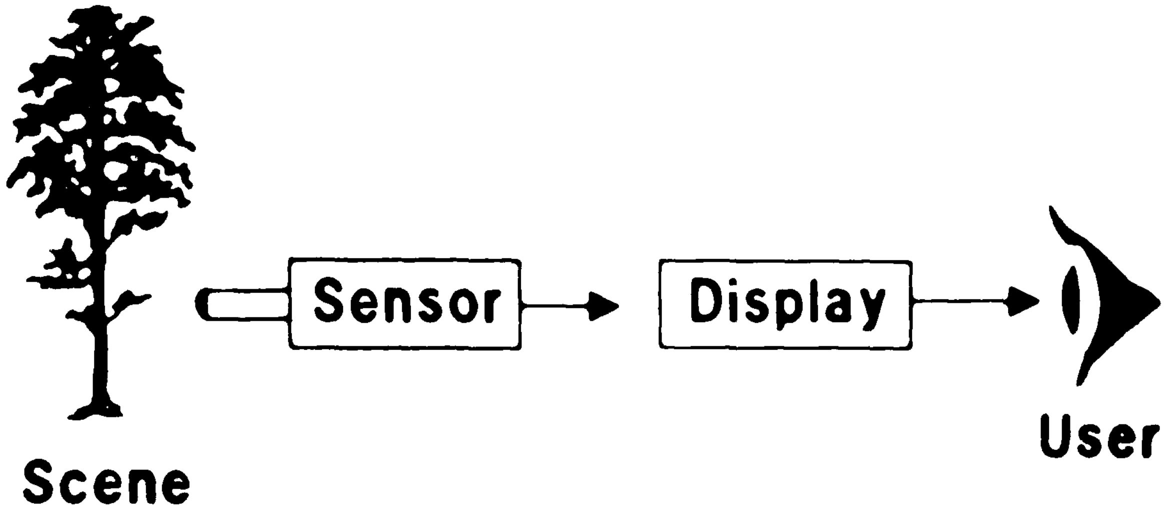

Figure 1. Night vision device (NVD) block diagram.

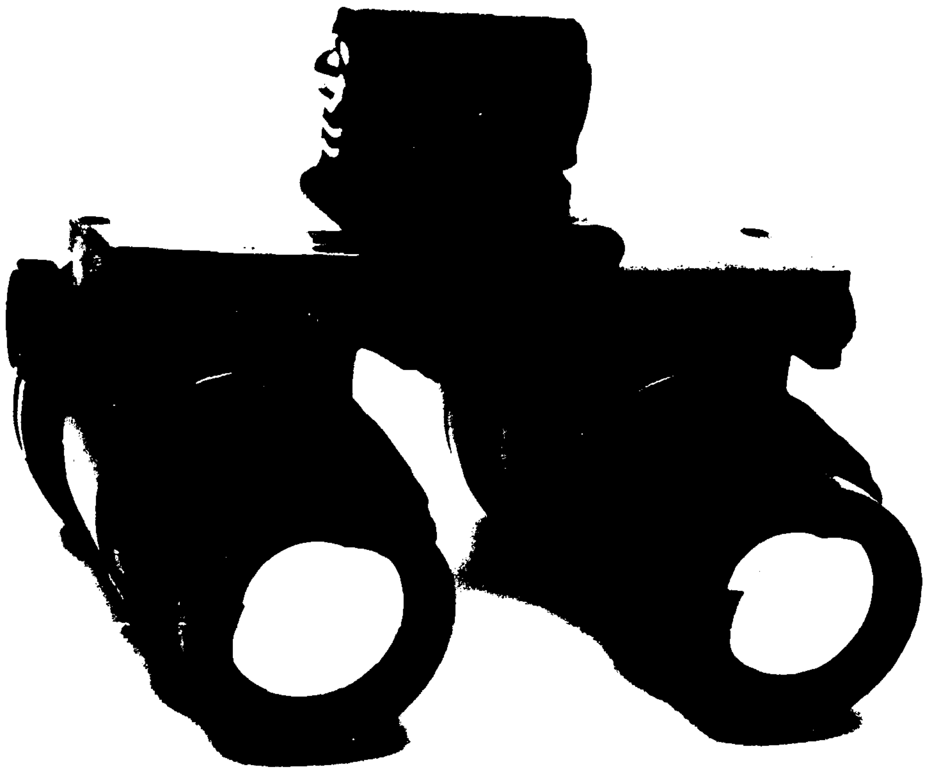

Figure 2. Aviator's Night Vision Imaging System (ANVIS).

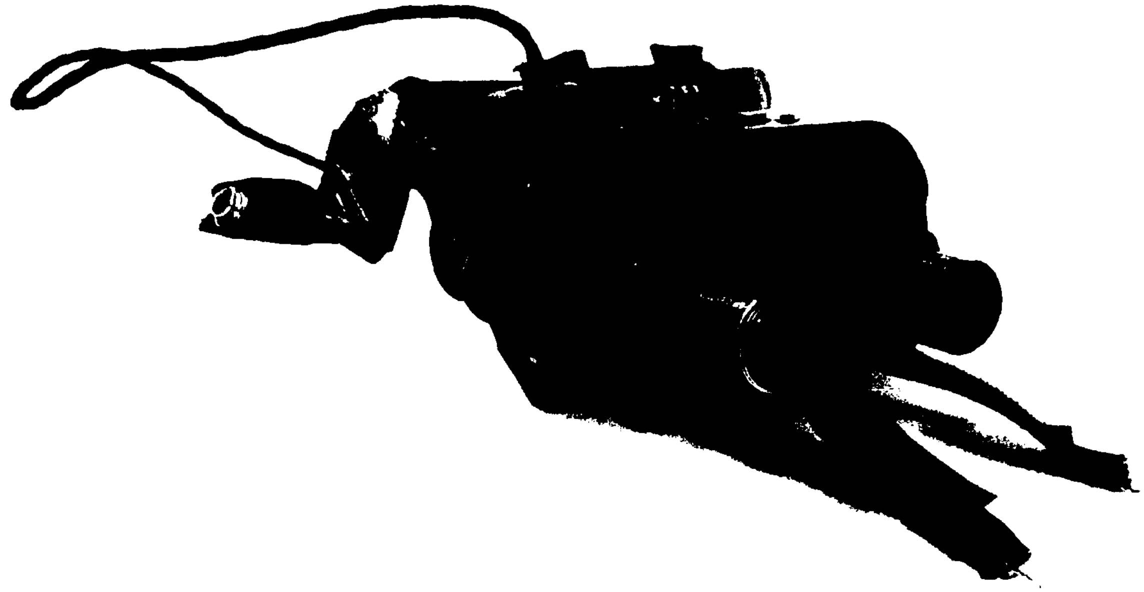

Figure 3. AN/PVS-5 Night Vision Goggles (cut-a-way version).

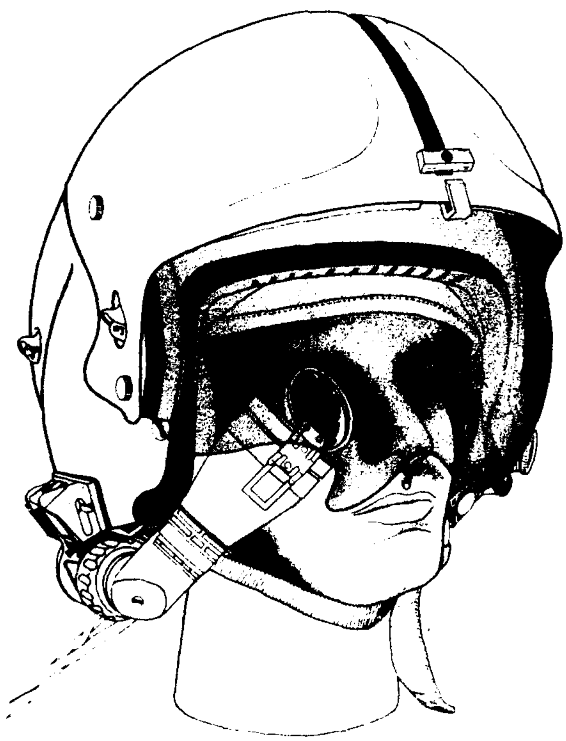

Figure 4. Integrated Helmet and Display Sighting System (IHADSS).

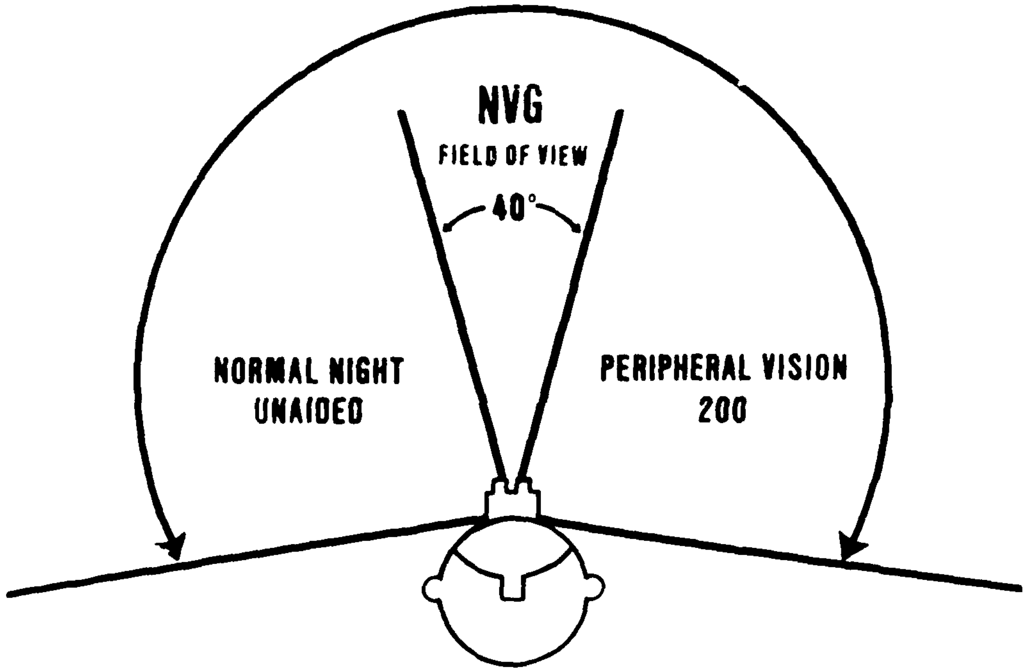

Figure 5. Instantaneous field-of-view for the human visual system and current helmet mounted displays (HMDs).

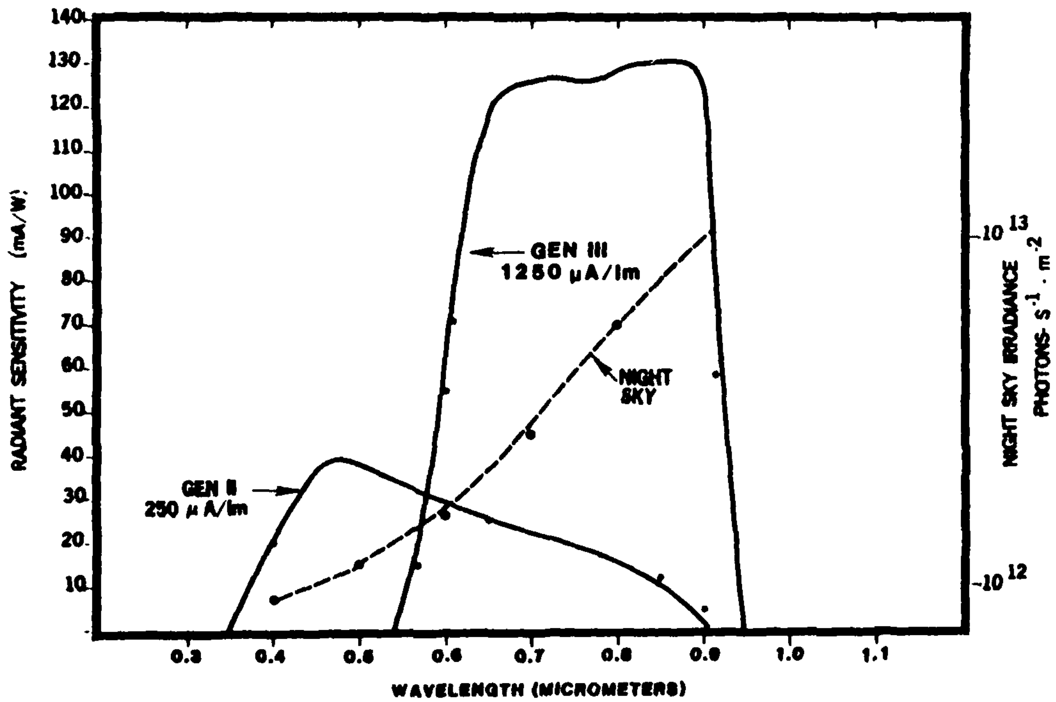

Figure 6. Comparison of sensitivities between second and third generation image intensifier tubes.

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